(51) International Patent Classification 6 :	A1	(11) International Publication Number: WO 95/19689
H04Q 11/00		(43) International Publication Date: 20 July 1995 (20.07.95)

(54) Title: INTERCONNECTED PASSIVE OPTICAL NETWORKS
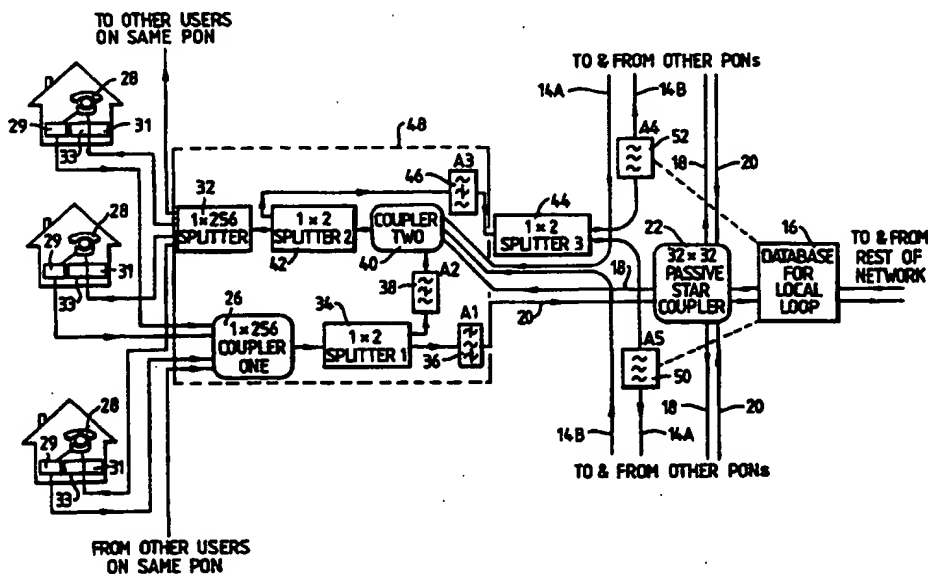
(57) Abstract

An optical communications network comprising a plurality of passive optical networks (PONs) connected in a ring in PON address order, in which communication channels between terminals are wavelength multiplexed. Each optical link between adjacent PONs includes a tunable wavelength filter, and a common wavelength allocation database is arranged dynamically to select wavelengths for a connection and to provide corresponding control signals to the appropriate filters such that the allocated wavelengths for a connection can pass over only the transmission path between the terminals. Thus the same wavelengths can be re-used for another connection whose transmission path does not overlap with any existing transmission path involving those wavelengths.

- 1 -

INTERCONNECTED PASSIVE OPTICAL NETWORKS

This invention relates to wavelength management in an optical communications network employing wavelength division
5   multiplexing.

It is known from "A Precompetitive Consortium on Wide-Band All-Optical Networks", by S B Alexander et al., Journal of Lightwave Technology, Vol. 11, No. 5/6, May 1993, to configure an all-optical network (AON) as a hierarchical tree
10 structure in which a plurality of level-0 AONs, having optical terminals and also known as passive optical networks (PONs), are connected to level-1 AONs which in turn are connected to level-2 AONs. Each PON has a fixed frequency-selective local bypass for wavelengths which are pre-
15 allocated for use at level-0, thus enabling the same wavelengths to be used by each PON. To connect with a terminal on a different PON, a terminal must use a wavelength not in the level-0 set to reach its associated level-1 AON where the wavelength is routed either to a PON on that level-
20 1 AON or upwards to an associated level-2 AON to reach a PON on a different level-1 AON. Frequency changers may be used in this latter case.

International   Application   No.   PCT/US92/03256 (International Publication No. WO 92/18890) discloses an
25 optical network of nodes and connecting links of pairs of fibres carrying optical signals in opposite directions. Each node comprises an optical switch in the form of a controllable linear divider-combiner (LDC) assembly which under the control of a Network Control Centre performs power
30 dividing and combining for each of the wavebands from a waveband demultiplexer to route signals from an input port to an output port.

The articles "Linear Lightwave Networks: Performance Issues" by T E Stern et al., Journal of Lightwave Technology,
35 Vol. 11, No. 5/6, May/Jun 1993, and "Linear Lightwave N tw rks: How Far Can They Go?", by T E St rn, C nf rence Record, IEEE Global T l communications Conf r nce, 2-5

- 2 -

December 1990, Vol. 3, pages 1866-1872, also disclose optical
nodes employing an LDC as an optical switch performing
controllable waveband selective optical signal routing,
combining, and splitting.   The switch proper comprises
5   controllable power dividers (also known as directional
couplers) disposed so that each input port can be
controllably connected to any output port.   In preferred
arrangements there are several switches, each having its
input ports connected to the output of a common waveband
10   demultiplexer and its output ports connected to a common
waveband multiplexer.   In this way, wavelengths in a
waveband can be confined to limited regions of a large
network, and the waveband can be reused in other parts of the
network.

15   The article "The LAMBDANET Multiwavelength Network:
Architecture, Applications, and Demonstrations", by M S
Goodman, et al., IEEE Journal on Selected Areas in
Communications, Vol. 8, No. 6,August 1990, discloses a
plurality of nodes, each of which transmits on a respective
20   wavelength, connected to a star coupler so that each node
output is broadcast to each other node.   In order to separate
the received set of wavelengths a node may use wavelength
tunable filters and receivers, or multiple fixed receivers.
        The paper "Multiwavelength Ring Networks for Switch
25   Consolidation and Interconnection", by S S Wagner et al.,
Conference   Record,   International   Conference   on
Communications, 14-18 June 1992, Vol. 3, pages 1173-1179,
discloses a plurality of Central Offices (COs) connected by
a 2-fibre multiwavelength-ring network.   One CO acts as a
30   switch, and each of the other COs sends transmissions to the
switching CO on a respective wavelength on both fibres (one
clockwise and the other anti-clockwise for protection in case
the ring were to be broken).   The switching CO receives all
wavelengths from the other COs, and retransmits on the
35   corresponding wavelength t th appropriat destinati n CO,
which extracts the incoming messag on its associated
wavelength and inj cts an utgoing m ssag on th sam

- 3 -

wav length using a d dicated optical add-drop filt r.   In a
variant using an inner pair of fibres for transmission to the
Switching CO and an outer pair of fibres for reception from
the Switching CO, wavelengths can be pre-allocated for direct
5 connections between COs (i.e. not passing through the
switch), these wavelengths being directly coupled at the
switching CO from the inner fibres to the outer fibres.

According to a first aspect of the present invention
5 there is provided an optical communications network
comprising: a plurality of connected passive optical networks
(PONs) in which communication channels between terminals are
wavelength multiplexed, at least some of the PONs being
arranged to relay an optical signal on an incoming link to
10 each of a plurality of outgoing links; and connection control
means for dynamically allocating a first wavelength for a
connection from a first terminal connected to a first PON to
a second terminal connected to said first PON or to a
different PON, and for dynamically controlling respective
15 tunable wavelength filter means on links associated with the
PON or PONs having the first and second terminals, and with
any intermediate PONs, to block said dynamically allocated
wavelength on any such associated link not being a link which
is part of the transmission path from the first terminal to
20 the second terminal.

Networks in accordance with the present invention
contrast with those of the abovementioned prior art in that
they do not employ an optical switch, but have a coupling
arrangement for broadcasting each incoming optical signal to
25 each outgoing fibre link and use tunable wavelength filters
to block outgoing transmissions from a PON to its
neighbouring PONs instead of the prior art arrangement of
filters disposed at the receiving node to select the required
wavelength from a set of incoming wavelengths. In this way,
30 by appropriate control of the filters, a wavelength can be
blocked on c rtain outgoing links and allow d to pass on a
d sir d link or links whereby only the int nd d destination
PON, or an int rm diate PON, r ceives th transmitted

- 4 -

wavelength, and sinc the wavel ngth is confined to th PONs
and links associated with that connection it can be
dynamically re-allocated for use with any other connection
which does not involve a common PON. Such a network provides
5 a network controller considerable scope in the establishment
of transmission paths for connections and in the selection
(including re-use) of the transmission wavelength(s).

In a first preferred network of the first aspect, the
connection control means is arranged dynamically to allocate,
10 for said first connection, a second wavelength for
transmission from the second terminal to the first terminal,
and dynamically to control said respective tunable wavelength
filter means on links associated with the PON or PONs having
the first and second terminals, and with any intermediate
15 PONs, to block said second dynamically allocated wavelength
on any such associated link not being a link which is part of
the transmission path from the second terminal to the first
terminal.

In a second preferred network of the first aspect, the
20 PONs are linked serially in address order, each having an
outgoing link to each neighbouring PON, the respective
tunable filter means associated with links in the direction
of increasing PON address order being arranged to block
permanently wavelengths allocated, in use, by the connection
25 control means to terminals for transmission to PONs of lower
address, the respective tunable filter means associated with
links in the direction of decreasing PON address being
arranged to block permanently wavelengths allocated to
terminals for transmission to PONs of higher address whereby,
30 in use, only the tunable filter means associated with the
outgoing links of the respective destination PONs to
neighbouring PONs not associated with that connection are
controlled to block the respective wavelength.

In such a second preferred network, preferably the
35 connection control m ans is arrang d to allocate for
transmission in on direction wavelengths which are spac d

- 5 -

and alternate with wavelengths which can be allocated for transmission in the other direction.

Alternatively, the connection control means is arranged to allocate for transmission in one direction wavelengths within a first band, and to allocate for transmission in the opposite direction wavelengths within a second band.

Preferably, the connection control means is arranged to allocate for each connection a pair of wavelengths, each pair being spaced by a constant amount.

According to a second aspect of the present invention there is provided a method of establishing communication between terminals on an optical communications network comprising a plurality of optically linked passive optical networks (PONs) in which communication channels between terminals are wavelength multiplexed and at least some of the PONs being arranged to relay an incoming optical signal to each of a plurality of outgoing links, the method comprising the steps of dynamically allocating a first wavelength for transmission from a source terminal to a destination terminal for a first connection, and dynamically controlling respective tunable wavelength filter means on links associated with the PON or PONs having the source and destination terminals, and with any intermediate PONs, to block said allocated wavelength such that the transmission is confined to the transmission path between the source and destination terminals, thereby enabling said allocated wavelength to be used for a simultaneous connection over a non-overlapping transmission path.

Preferably, there is included the step of dynamically allocating, for said first connection, a second wavelength for transmission from the destination terminal to the source terminal, and dynamically controlling said respective tunable wavelength filter means on links associated with the PON or PONs having the source and destination terminals, and with any intermediate PONs, to block said s cond allocated wavelength such that th transmission from the destination

- 6 -

terminal is confined to the transmission path between the
source and destination terminals.

Preferably, the PONs are linked serially in address
order, and including permanently blocking one wavelength of
5 said first and second allocated wavelengths on each link
leading from a PON to a PON of lower address, permanently
blocking the other wavelength of said allocated wavelengths
on each link leading from a PON to a PON of higher address,
selectively blocking the said one wavelength on the link
10 leading from the destination PON to a PON of higher address,
and selectively blocking said other wavelength on the link
leading from the source PON to a PON of lower address.

There may be included the step of dynamically
allocating each further connection having a transmission path
15 overlapping that of the first connection a respective
different pair of transmission wavelengths. The lower
wavelengths of the pairs may be spaced apart by a
predetermined difference, the upper wavelengths being spread
apart by the same difference.

20   Preferably, each pair comprises adjacent wavelengths.

All the lower wavelengths of the pairs may be grouped
in one group in wavelength order, the upper wavelengths being
grouped in an adjacent group.

Embodiments of communications networks in accordance
25 with the present invention will now be described by way of
example with reference to the drawings in which:-

Figure 1 is a schematic diagram of a communications
network;

Figure 2 is a schematic diagram of the component parts
30 of a PON forming part of the network of Figure 1;

Figure 3 is a schematic diagram of a modified part of
the network of Figure 1;

Figure 4 is a schematic diagram of another modified
part of the network of Figure 1;

35   Figur 5 is a schematic diagram f one embodiment of
an lectronically tunable wavel ngth filter f r us in a
n twork of th pres nt invention; and

Figure 6 is a schematic diagram of a part of an alternative embodiment of the filter of Figure 5.

In Figure 1 a communications network 10 in accordance with the present invention comprises thirty one passive
5 optical networks (PONs), but for convenience only eight PONs 12-1 to 12-8 are shown coupled together in the form of a ring by pairs of optical links 14-1 to 14-8. One link A of pair 14-1 carries signals from PON 12-1 to PON 12-2, i.e. is an outgoing link with respect to PON 12-1, and the other link B
10 of pair 14-1 carries signals in the opposite direction, i.e. is an outgoing link with respect to PON 12-2, and correspondingly for the other pairs 14-2 to 14-8.

Network 10 constitutes a local access network for a public communications network, equivalent to that known as a
15 local exchange and its local exchange lines, and in this context terminals 28 are constituted by telephones and other such telecommunications apparatus, and connections between terminals are generally referred to as calls.

Centrally disposed within the ring of PONs is a
20 wavelength allocation database 16, and each PON communicates with the database 16 via an upstream link 18-1 to 18-8 and a downstream link 20-1 to 20-8, and a passive star coupler 22 (Figure 2).

Within the head-end of each PON 12 is an optical
25 receiving means 24 comprising a 1 x 256 coupler 26 (Figure 2) receiving upstream optical transmissions from all its terminals 28, and an optical transmitting means 30 comprising a 1 x 256 splitter 32 (Figure 2) feeding an optical signal to the downstream links to its terminals 28. The receiving
30 means 24 provides an output to the downstream link 20 and to the transmitting means 30 which itself receives an input from the upstream link 18 and provides outputs to appropriate links to the neighbouring PONs.

The PON 12 is normally fully-loaded with 250 terminals
35 28, leaving six of the inputs and outputs spar .

Referring now to Figur 2, which shows the c mpon nt parts f a PON suitabl for us in th n twork 10, the utput

- 8 -

of coupler 26 feeds a 1 x 2 splitter 34 one output of which
is coupled to an input of the star coupler 22 via a
wavelength filter or absorber 36 and link 20, and the other
output is coupled to a wavelength filter or absorber 38.
5 Filter 38 is designed to pass all wavelengths except a first
predetermined wavelength, λ_1, and filter 36 is designed to
pass only the first predetermined wavelength, λ_1.

The output of filter 38 feeds into an input of a 1 x
4 coupler 40 whose output feeds the input of a 1 x 2 splitter
10 42.   One output of splitter 42 feeds the input of the
splitter 32, and the other output of splitter 42 is coupled
to the input of a 1 x 2 splitter 44 via a wavelength filter
or absorber 46 which is designed to pass all wavelengths
except λ_1 and a second predetermined wavelength, λ_2.

15   Filters 36 and 38 are integral with the splitter 34,
and filter 46 is integral with the splitter 42, although for
convenience they are shown as separate in Figure 2.   The
head-end components 26, 32, 34, 36, 38, 40, 42 and 46 are
contained together in a unitary construction 48.

20   The two outputs of splitter 44 feed respective
electronically tunable wavelength filters or absorbers 50 and
52 designed to filter out, i.e. block, wavelengths under the
control of the database 16.   The filters 50 and 52 feed
respective optical fibres 14A and 14B extending in opposite
25 directions to adjacent PONs 12 on the ring, and the
corresponding optical fibres 14B and 14A from those adjacent
PONs are coupled to inputs of coupler 40, whose fourth input
is coupled to an output of the star coupler 22 via link 18.

Each terminal 28 comprises a tunable transmitter 29
30 having an operating range from 1500nm to 1530nm and which is
controllable to generate any one of 200 discrete wavelengths
in that range, control circuitry (not shown) responsive to
information in a receive status packet from the database to
provide the appropriate control signal to the transmitter, a
35 narrow band receiver 31 for continuously monitoring the
control channel (λ_1 to detect contention situations, and λ_2 to
receive status packets), and a tunable receiver 33

- 9 -

controllable to receive any one of the transmission
wavelengths in response to a control signal from the control
circuitry.

In an alternative embodiment wherein the tunable
5 receiver 33 is able to step from one received wavelength to
another in a few nanoseconds, the separate narrowband
receiver 31 is omitted and its function is provided by the
tunable receiver 33.

When a terminal, say A on PON 12-1, wishes to
10 communicate with another terminal on the ring, say A' on PON
12-1, it sends a call set-up request on wavelength λ_1 to the
database 16. This request is short, less than 1×10^{-4} sec,
and comprises address fields for the source and destination
terminals, and corresponding fields for the transmission
15 wavelengths to be used by the terminals, which latter fields
are initially empty.

The call set-up request travels via coupler 26,
splitter 34, and filter 36 to star coupler 22, and thence to
database 16 and all other terminals. Each terminal operates
20 a contention protocol so that if another terminal wishes to
send a call set-up request to the database, it will wait
until completion of the current call set-up request.
However, if that other terminal has already sent its own call
set-up request, the terminals and the database can detect
25 that two (or more) requests are present on the network at the
same time. The database will ignore overlapping requests,
and the terminals will repeat their requests after respective
random delays in accordance with the contention protocol, as
is known in the art.

30   Upon receipt of a request, the database 16 will
allocate a pair of wavelengths, λ_3 and λ_4, making an entry
that these wavelengths have been allocated for communication
between the two terminals. The same pair of wavelengths can
be used for further calls provided that their transmission
35 paths are kept s parat so that th r is n overlapping
portion.

- 10 -

The database 16 will enter the identities of λ_3 and λ_4 in the fields of the call set-up request and transmit the modified request to the star coupler 22 at wavelength λ_2. Thus source terminal A will know that it is to transmit at λ_3,
5 and destination terminal A' will know that it is to transmit at λ_4.

The database 16 keeps a record of the current usage of all wavelengths, other than the pair used for the control and status packets, for each of the PONs of the network. Thus
10 for a proposed call between PON 1 and PON 3, the database will check whether for the first pair of transmission wavelengths, say λ_3 and λ_4, there is a set "use" flag for λ_3 in any of the locations $L_{3.1}$ to $L_{3.3}$ corresponding to PONs 1 to 3 and λ_3. If there is no such flag, the database will
15 allocate that pair, setting the flag in location $L_{3.1}$ and in location $L_{4.3}$.

If any of the locations $L_{3.1}$ to $L_{3.3}$ had contained a set flag, the database would have proceeded to perform the same check for the next pair, and so on.
20   In the general case, where a call is being set up between terminals on PONs a and b, a being lower in numerical value than b, the database will determine the shortest route between PON a to PON b so as to maximise re-use of λ_3 and λ_4 for other potential calls on the network. For a small
25 network of PONs in a ring with no additional links between non-adjacent PONs, this will be a simple matter of comparing the values of (b-a) and (a+N-b), where N is the number of PONs in the ring, to determine whether the shorter path is via PON a+1 etc, or via PON b+1 etc. For example, a call
30 between PONs 3 and 8, the first value will be 5, and the second value will be 3. Therefore, the shorter route will be via PONs 1 and 2, treating PON 1 as PON (8+1).

When a call is established, the database will set the use flag for every PON through which the optical signals
35 pass. Thus for a call betw en PONs 3 and 8 via PONs 1 and 2, all those PONs will hav their flags s t so as to pr v nt th allocation of λ_3 and λ_4 for any furth r call involving any of

- 11 -

those PONs. If th re is an addition link b tw en PONs 3 and
8 then only these two PONs will have their flags set. It is
only necessary to have one use flag for the pair of
wavelengths, but, if desired, there can be respective use
5 flags for λ_3 and λ_4.

For "local" calls, i.e. between two terminals on
network 10, wavelengths in the window 1500nm to 1530nm are
used. With a spacing of 0.15nm, 200 wavelengths are
available which are grouped in pairs, say λ_1 λ_2, λ_3 λ_4, up to
10 λ_{199} λ_{200}.

A transmission protocol is used which provides that
the lower of an allocated pair of wavelengths will be
transmitted around the ring in the direction from the lower
network address terminal to the higher network address
15 terminal, in number order, i.e. clockwise from PON 12-1 to
PON 12-2, as seen in Figure 1, but not from PON 12-1 to PON
12-8, and correspondingly in the opposite direction for the
other wavelength of the pair. Thus for a call between a
terminal on PON 12-1 to a terminal on PON 12-8, the database
20 will allocate the lower wavelength to the terminal on PON 12-
8.

The protocol thus determines that all filters 52 can
permanently filter out the wavelengths λ_3, λ_5, λ_7 etc, and all
filters 50 can permanently filter out the wavelengths λ_4, λ_6,
25 λ_8 etc. Thus when a terminal transmits onto the ring, the
optical signals can proceed only in one direction, that
direction depending on which wavelength of the pair is being
used.

The database, which constitutes a connection control
30 means of the present invention, will send a controlling
signal to the relevant filter 50 or 52 at the PON having the
destination terminal to filter out the transmitted wavelength
and thus confine the wavelength to that transmission path
between the communicating terminals.

35   Wher communicating terminals ar on th sam PON, as
are terminals A and A', filter 50 at that PON is contr lled

- 12 -

to filter out λ_3 and filter 52 is controlled to filter out λ_4, thus confining those wavelengths to that PON.

In this embodiment, a pair comprises neighbouring wavelengths of the group of 200 wavelengths, so that filters
5   50 are tunable to filter selectively the wavelengths λ_3, λ_5 etc, and correspondingly for filters 52. Thus adjacent selectable wavelengths to be filtered are spaced by 0.30nm.

In an alternative embodiment where technology permits the selectable wavelengths to be spaced by 0.15nm, the
10 protocol is modified such that instead of the wavelengths for call set-up being λ_1 and λ_2, and call pairs being λ_3 and λ_4, etc, the call set-up pair comprises λ_1 and λ_{101}, and the call pairs are λ_2 and λ_{102}, λ_3 and λ_{103}, etc. This means that filter 50 is controlled to select λ_2 to λ_{100} and is designed
15 permanently to filter out λ_{101} to λ_{200}, and filter 52 correspondingly is controlled to select λ_{102} to λ_{200} and is designed permanently to filter out λ_2 to λ_{100}. By this means, where say a terminal on PON 12-1 communicates with a terminal on PON 12-2, the terminal with the lower network address will
20 know that it has to transmit on the lower of the two allocated wavelengths λ_x and receive on the higher, λ_{100+x}, and correspondingly for the other terminal. The database can effectively provide the identities of the two transmission wavelengths by giving the identity of say one wavelength, say
25 λ_x, together with an indication of whether the lower addressed terminal will transmit on the lower wavelength (a Normal flag set, say) or, where the call involves the link between PON 12-1 and PON 12-8 (i.e. the highest numbered PON), the higher addressed terminal will transmit on the lower wavelength (the
30 Normal flag not set). In another embodiment, filters 50 and 52 filter out λ_1 and λ_{101}, respectively, either permanently or under control of the database, and filter 46 is omitted.

In Figure 1, by appropriate control of the filters 50 and 52 of the relevant terminals, independent calls exist at
35 λ_3 and λ_4 for pairs of terminals BB', CC', and DD'. However, for the call between terminal E on PON 12-2 and terminal E' on PON 12-1 the database will have allocated a different pair

- 13 -

of wavelengths λ_5 and λ_6. For the call between terminal E on
PON 12-2 and terminal E' on PON 12-1, filter 52 of PON 12-1
is controlled to filter out λ_6 (it permanently filters out
λ_5), filter 50 of PON 12-1 permanently filters out λ_6, filter

5 52 of PON 12-2 permanently filters out λ_5, and filter 50 of
PON 12-2 is controlled to filter out λ_5 (it permanently
filters out λ_6). This confines the wavelengths to the
selected transmission path between the terminals including
the optical links between adjacent PONs. It will be

10 appreciated that only two tunable filters need to be
controlled by the database, one for each direction of
transmission so as to stop the transmitted signal from
passing beyond the destination PON.

For the call between terminal D on PON 12-5 and

15 terminal D' on PON 12-2, only filter 50 of PON 12-5 is
controlled by the database 16 to filter out λ_3 and prevent
that wavelength from reaching PON 12-6, and only filter 52 of
PON 12-2 is controlled by the database 16 to filter out λ_4 and
prevent that wavelength from reaching PON 12-1. All filters

20 50 permanently filter out λ_4 and all filters 52 permanently
filter out λ_3.

If there is a large amount of traffic between, say,
terminals on PON 12-1 and terminals on PON 12-3 and all
available wavelengths are in use, the terminals on PON 12-2

25 cannot make any calls, but terminals on PONs 12-4 to 12-8 can
communicate between themselves because wavelengths can be
reused over non-lapping paths. Where such a situation is
identified an additional pair of fibres 61 is connected
between PONs 12-1 and 12-3 as shown in Figure 3 in which

30 splitter 44 is replaced by a 1 x 3 splitter 45, and coupler
40 is replaced by a 1 x 5 coupler 41, then splitter 45 of PON
12-1 is coupled by an optical fibre to coupler 41 of PON 12-3
via a filter 62, and splitter 45 of PON 12-3 is similarly
coupled to coupler 41 of PON 12-1 via a filter 63.

35 If a terminal on PON 12-1 is communicating at λ_7 via
fibres 61 with a terminal transmitting at λ_8 on PON 12-3, th n
in this case filters 50 of PONs 12-1 and 12-3 are controlled

- 14 -

to filter out λ_7, filters 52 of PONs 12-1 and 12-3 are controlled to filter out λ_8. Filter 63 of PON 12-3 filters out λ_7 (and all lower wavelengths of pairs to be used for communication between PONs 12-1 and 12-3) and filter 62 of
5   PON 12-1 filters out λ_8 (and corresponding all upper wavelengths). Where communication via fibres 61 is in the range 1500nm to 1530nm, terminals on PON 12-2 can communicate between themselves at the same wavelengths but transmission would not be permitted to pass out of PON 12-2 and interfere
10 with reception at PONs 12-1 and 12-3.

Alternatively, this direct communication between PONs 12-1 and 12-3 is in a separate window say 1530nm to 1565nm. For such an arrangement it will be appreciated that an additional filter 63 will be associated with filter 50 of
15 PONs 12-1 and 12-3 to filter out the lower wavelengths, and an additional filter 62 will be associated with filters 52 of PONs 12-1 and 12-3 to filter out the upper wavelengths.

Considering now a full-size ring of 31 PONs, one way of overcoming the transmission loss through the PONs would be
20 to have optical amplifiers spaced around the ring at, for example, the links between PONs 3 and 4, 7, and 8, 11 and 12, 16 and 17, 21 and 22, 26 and 27, 30 and 31.

The number of optical amplifiers required around the ring is dependent upon the gain of each amplifier and the
25 loss through the PONs. The greater the optical gain, the more PONs between amplifiers. If desired, a larger number of lower gain amplifiers can be arranged around the ring.

In alternative embodiments, additional optical links 58 are provided between non-adjacent PONs. Where a PON
30 terminates a single additional link then it will have components as shown in Figure 3, link 61 being equivalent to a link 58, and where it terminates two additional links it will have the components as shown in Figure 4 which differ from the Figure 3 arrangement in that coupler 41 has been
35 r placed by a 1 x 5 coupler 54, splitter 45 has been replaced by a 1 x 4 splitter 56, link 58A-1 f ds th signal from one of the outputs of splitter 56 via a tunabl filter 50' to the

- 15 -

coupler 54 of a non-adjacent PON y, link 58B-1 receives the
signal from a tunable filter 52' of PON y, and,
correspondingly, link 58A-z carries the signal from splitter
56 via filter 52' to PON z, and link 58B-z feeds the signal
5 from filter 50' of PON z to coupler 54. In such a network,
all filters 50 and 50' are identical, and all filters 52 and
52' are identical.

      In alternative embodiments, the filters 50' and 52'
are replaced by filters in which each wavelength is
10 selectively absorbed or passed instead of, as in filters 50
and 52, one wavelength of each pair being permanently
absorbed.

      Referring now to Figure 5, which shows an
electronically tunable wavelength filter 50 fabricated using
15 bulk optics, there is shown an incoming optical fibre 64
(from splitter 44) optically coupled to a demultiplexer 66
(in the form of a Fabry Perot device) which disperses the
input wavelengths such that each wavelength emerges from the
demultiplexer 66 at a respective angle. Disposed in the path
20 of the emergent wavelengths are respective movable mirrors
68-1 to 68-N (only four being shown), where N may be 200.

      Each of the mirrors 68 is movable between a first
stable position in which it reflects its input wavelength
towards a multiplexer 70, which is optically coupled to the
25 outgoing optical fibre 14A, and a second stable position in
which it reflects its input wavelength away from the
multiplexer 70. Each mirror has an associated actuator 72
which drives the mirror into the first position in response
to an electrical signal representative of a logic one
30 condition (On), and into the second position for a logic zero
condition (Off).

      The database 16 controls the filters 50 and 52 by
sending logic signals to the respective actuators 72 to
control which wavelengths are absorbed and which are not.

35   The filt r pr p r may compris a numb r of secti ns
(not shown) each arranged to handl a r sp ctive group of the
wavelengths us d in th n twork, and in this case the

- 16 -

sections will be coupled to the fibres 64 and 14A by respective splitters (not shown) and couplers (not shown).

In the filter of Figure 5 all the mirrors are tunable. In a variant for use with a network in which one wavelength
5 of each pair is permanently absorbed, there is no need to provide any mirrors for these filtered wavelengths because they can be absorbed in any suitable manner.

In Figure 6, which shows one component of an alternative fabrication of the filter 50 using integrated
10 optics, the fibre 64 is coupled (via a splitter, not shown) to the input of a silicon device 74 and the fibre 14A is coupled (via a coupler, not shown) to the output of the device 74. A central portion of device 74 comprises an electro-optical device 76 whose refractive index varies with
15 an applied electrical signal. An InP-doped optical transmission path exists from the input of device 74, through the electro-optical device 76, to the output of device 74. Device 76 responds to an actuating electrical signal from database 16 to alter its value of refractive index and cause
20 the wavelengths to follow respective curved paths from the input of device 76 to its output region, only one wavelength passing out of device 76, and out of device 74, while all other wavelengths are absorbed by device 76. In this case the actuating signal will be analogue in nature as opposed to
25 the digital control required for the embodiment of Figure 5.

It will be understood that the more additional links that a network has, ranging from links which by-pass one PON up to links which by-pass many PONs (say, thirteen or even fifteen), the greater the likelihood of there being a low-hop
30 path between a source and a destination PON. On the other hand, as the number of outputs increases on the output splitter (45, 56) there will be increased signal loss through a PON.

Where network 10 is an access network of a national
35 communications network, there will be links from network 10 to the next hi rarchical level, say th c re n tw rk of th national n twork, and optical communication on such links

- 17 -

will be in the window 1530nm to 1565nm and employ erbium
doped fibre amplifiers (EDFAs) to compensate for loss of
signal strength over the long run from the network 10 to its
nearest core network switching node.   In such a case, any
5   communication over links 61 should not be in the EDFA window
to keep this free for calls via the core network.

        In greater detail, a call set-up request, also called
a control packet, comprises four fields, the first contains
the identity (address) of the destination terminal or node
10 (26 bits), the second contains the bandwidth requested by the
source terminal for the transmission (8 bits), the third
contains the identity (address) of the source terminal or
node (26 bits) and the fourth contains error checking or
correction information and the time that the request was sent
15 (40 bits).   At a data transmission rate of about 2M bit/s
this would be transmitted and received at the database in
less than 10^{-4}s.

        If the database receives a call set-up request which
is not corrupted by, for example, interference from another
20 request, it transmits a modified request, also called a
status packet, comprising four fields, the first containing
the   address   of   the   destination   terminal,   the   second
containing the address of the source terminal, the third
containing error checking or correction information, and the
25 fourth   containing   the   identities   of   the   respective
wavelengths to be used for the information transfer phase
(ITP), and the time that the status packet was sent.

        If for some reason, for example the destination
terminal is already engaged in a call with another terminal,
30 the database knows that the destination terminal is not free
to accept a call request, it sends a status packet at λ_2 with
the address of the source terminal in the first field.   The
source terminal will recognise that its own address is in
both the source and destination fields and know that the
35 databas   cann t send a status packet to the destination
t rminal   at   that   time.   With a sophisticated   calling
pr cedure   th   status   pack t   could   be   s nt   to   a   busy

- 18 -

destination terminal to generate, for example, a call waiting signal.

When the ITP has finished the source terminal will send a call shut-down request or packet to the database which
5 responds by altering the entries in its records to the effect that the terminals are now free and not busy, that the two allocated wavelengths are available for use over any path not already in use at those wavelengths, and that all the tunable wavelength filters which had been under the control of the
10 database to filter out one or other or both of the wavelengths for the call just finished can now be controlled to pass those wavelengths if required.

The pairs of optical links 14 of network 10 are formed of monomode fibre without EDFA, so for a call from network 10
15 via the core network, wavelengths will be chosen within the EDFA window of 1530nm to 1565nm, but local calls, i.e. those not involving the core network, use wavelengths outside this region.

Customers making local calls are allocated basic 2.048
20 Mbit/s channels at wavelengths less that 1530nm, and channels at about 10M bit/s at wavelengths greater than 1565nm.

In the above described embodiments, filters 50 and 52 on an optical link between adjacent PONs have been disposed at the transmitter end of the optical link. If desired, they
25 could be disposed at the receiver end of the links, or at any convenient position along the links.

Instead of network 10 being serially connected in a ring as in Figure 1, it could be a fully or partially connected mesh network, in which case the filters should be
30 fully tunable so that any of the possible paths between a source PON and a destination PON can be chosen, or it could be a bus network, which is effectively a broken ring.

In a variant the database allocates a single wavelength for communication between a source terminal, i.e.
35 a t rminal which requests a connection, and a d stinati n terminal, and the sourc t rminal mploys a ranging and synchronisation protocol for establishing a two time slot

- 19 -

time division multiplex communication between the terminals.
The protocol would ensure that the receiver of the source
terminal is inhibited during transmission from the source
transmitter and at least until reception of the reflection of
5 the source terminal transmission from the destination PON.
In order for the destination terminal to use the same
wavelength, filters 52 of the destination PON and any
intermediate PONS are not controlled to block the wavelength
transmitted from the source terminal, whereby the same
10 wavelength transmitted from the destination terminal will
pass through filters 52 and reach the source terminal.

In another variant one or more links incorporate a
respective wavelength translator.   The amount by which a
translator shifts received wavelengths may be fixed or be
15 controlled by the database. Translators may be used where it
is desired to use a particular wavelength or wavelengths for
a new call, but there will be wavelength contention or
conflict on the transmission path for the new call.   For
example, there may be an existing conference call between
20 many terminals using the particular wavelength(s) and a new
terminal is to be added to the conference without changing
the wavelength(s).   The newly added terminal can be
controlled by the database to use the shifted wavelength(s),
or the wavelength(s) shifted back by a further translator(s)
25 after the signal has passed the wavelength contention part of
the transmission path.

Whereas all the abovementioned links are optical fibre
links, a network may include links between PONs which
comprise non-optical paths and appropriate converters, for
30 example a radio or satellite link.

Whereas the abovedescribed specific embodiment and
variants relate to a telecommunications network in which the
terminals are telephones, facsimile machines and the like, it
will be appreciated that the network of the present invention
35 is equally applicable for th transport of data betw en
    l m nts of data processing apparatus and th lik wh r , for
example, such el ments are in th form of, for example,

- 20 -

individual cards comprising respective electro-optical
interfaces (optical transmitters and receivers) each
constituting a terminal of the present invention.   A
plurality of the cards, say those of a shelf, can be grouped
5 on a single PON, a plurality of such PONs in a large
apparatus comprising several shelves being inter-connected
for connections between any two terminals of the apparatus.
Such an arrangement may be used in computing apparatus,
database handling apparatus, and any apparatus where an
10 optical interface (i.e. terminal) requires selective
connection to another terminal, the nature of the information
to be transmitted on the network being immaterial.

- 21 -

CLAIMS

1.   An optical communications network comprising: a plurality of connected passive optical networks (PONs) in which communication channels between terminals are wavelength
5 multiplexed, at least some of the PONs being arranged to relay an optical signal on an incoming link to each of a plurality of outgoing links; and connection control means for dynamically allocating a first wavelength for a connection from a first terminal connected to a first PON to a second
10 terminal connected to said first PON or to a different PON, and for dynamically controlling respective tunable wavelength filter means on links associated with the PON or PONs having the first and second terminals, and with any intermediate PONs, to block said dynamically allocated wavelength on any
15 such associated link not being a link which is part of the transmission path from the first terminal to the second terminal.

2.   A network as claimed in Claim 1, wherein said connection control means is arranged dynamically to allocate,
20 for said first connection, a second wavelength for transmission from the second terminal to the first terminal, and dynamically to control said respective tunable wavelength filter means on links associated with the PON or PONs having the first and second terminals, and with any intermediate
25 PONs, to block said second dynamically allocated wavelength on any such associated link not being a link which is part of the transmission path from the second terminal to the first terminal.

3.   A network as claimed in Claim 1 or Claim 2, wherein
30 the PONs are linked serially in address order, each having an outgoing link to each neighbouring PON, the respective tunabl filt r m ans associated with links in the dir cti n of increasing PON address rd r b ing arranged to block p rmanently wavelengths allocated, in us , by the conn cti n

- 22 -

control means to terminals for transmission to PONs of lower
address, the respective tunable filter means associated with
links in the direction of decreasing PON address being
arranged to block permanently wavelengths allocated to
5 terminals for transmission to PONs of higher address whereby,
in use, only the tunable filter means associated with the
outgoing links of the respective destination PONs to
neighbouring PONs not associated with that connection are
controlled to block the respective wavelength.

10 4.   A network as claimed in Claim 3, wherein the
connection control means is arranged to allocate for
transmission in one direction wavelengths which are spaced
and alternate with wavelengths which can be allocated for
transmission in the other direction.

15 5.   A network as claimed in Claim 3, wherein the
connection control means is arranged to allocate for
transmission in one direction wavelengths within a first
band, and to allocate for transmission in the opposite
direction wavelengths within a second band.

20 6.   A network as claimed in Claim 5, wherein the
connection control means is arranged to allocate for each
connection a pair of wavelengths, each pair being spaced by
a constant amount.

7.   A method of establishing communication between
25 terminals on an optical communications network comprising a
plurality of optically linked passive optical networks (PONs)
in which communication channels between terminals are
wavelength multiplexed and at least some of the PONs being
arranged to relay an incoming optical signal to each of a
30 plurality of outgoing links, the method comprising the steps
f dynamically allocating a first wavelength for transmission
from a source terminal to a destinati n t rminal for a first
c nnection, and dynamically controlling r spectiv tunable

- 23 -

wavelength filter means on links associated with the PON or PONs having the source and destination terminals, and with any intermediate PONs, to block said allocated wavelength such that the transmission is confined to the transmission

5 path between the source and destination terminals, thereby enabling said allocated wavelength to be used for a simultaneous connection over a non-overlapping transmission path.

8. A method as claimed in Claim 7, including the step of

10 dynamically allocating, for said first connection, a second wavelength for transmission from the destination terminal to the source terminal, and dynamically controlling said respective tunable wavelength filter means on links associated with the PON or PONs having the source and

15 destination terminals, and with any intermediate PONs, to block said second allocated wavelength such that the transmission from the destination terminal is confined to the transmission path between the source and destination terminals.

20 9. A method as claimed in Claim 8, where the PONs are linked serially in address order, and including permanently blocking one wavelength of said first and second allocated wavelengths on each link leading from a PON to a PON of lower address, permanently blocking the other wavelength of said

25 allocated wavelengths on each link leading from a PON to a PON of higher address, selectively blocking the said one wavelength on the link leading from the destination PON to a PON of higher address, and selectively blocking said other wavelength on the link leading from the source PON to a PON

30 of lower address.

10. A method as claimed in either Claim 8 or Claim 9, including dynamically allocating each further connection having a transmission path ov rlapping that of th first

- 24 -

connection a respective different pair of transmission
wavelengths.

11.   A method as claimed in Claim 10, including spacing the
lower wavelengths of the pairs by a predetermined difference,
5 and correspondingly spacing the upper wavelengths of the
pairs by the same predetermined difference.

12.   A method as claimed in either Claim 10 or Claim 11,
wherein each pair comprises adjacent wavelengths.

13.   A method as claimed in either Claim 10 or Claim 11,
10 including grouping all the lower wavelengths of the pairs in
one group in wavelength order, and grouping all the upper
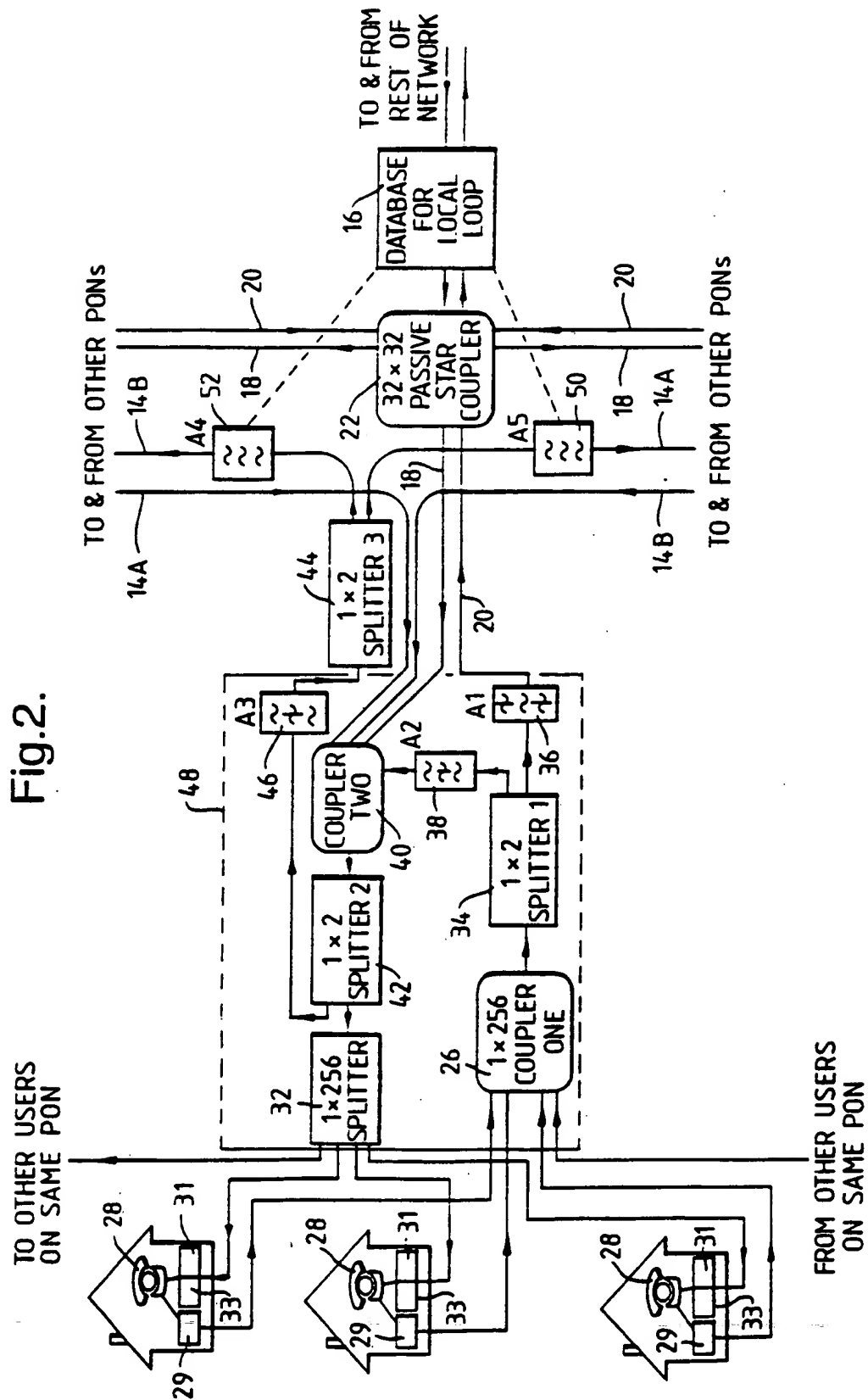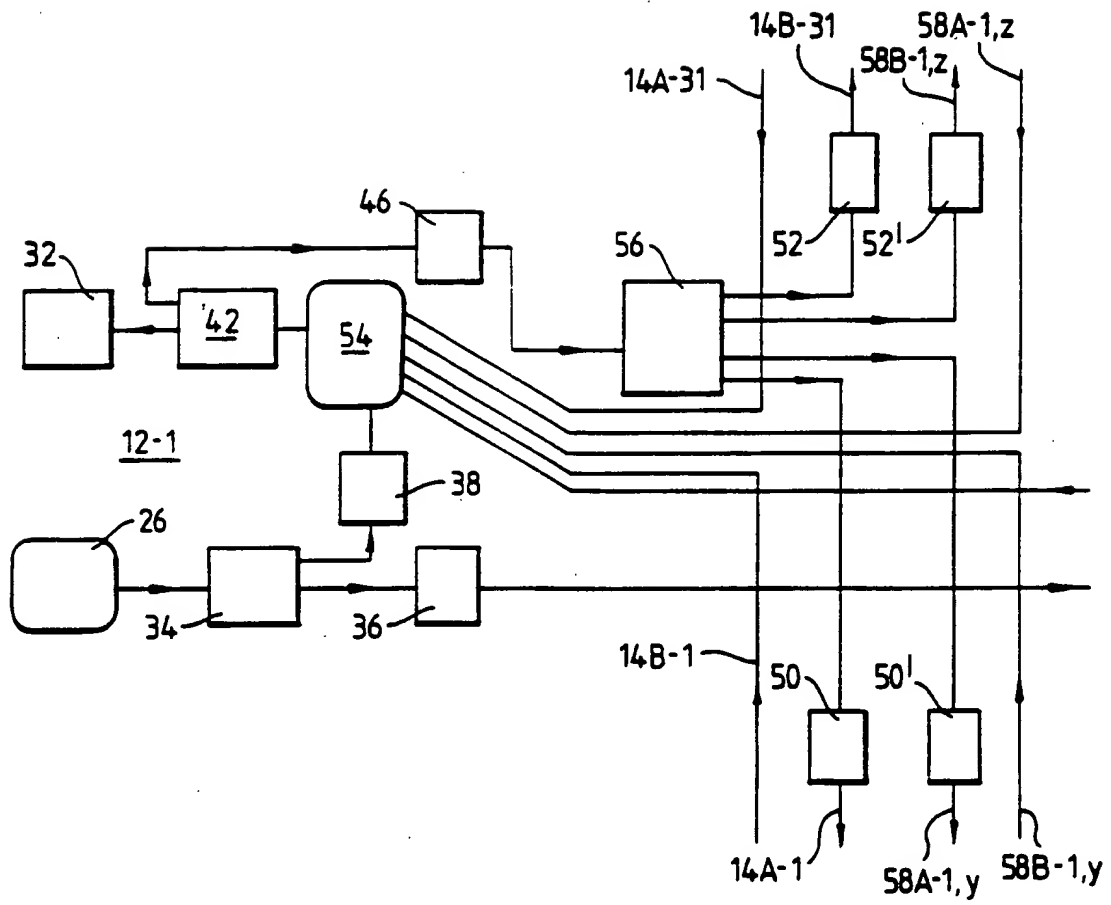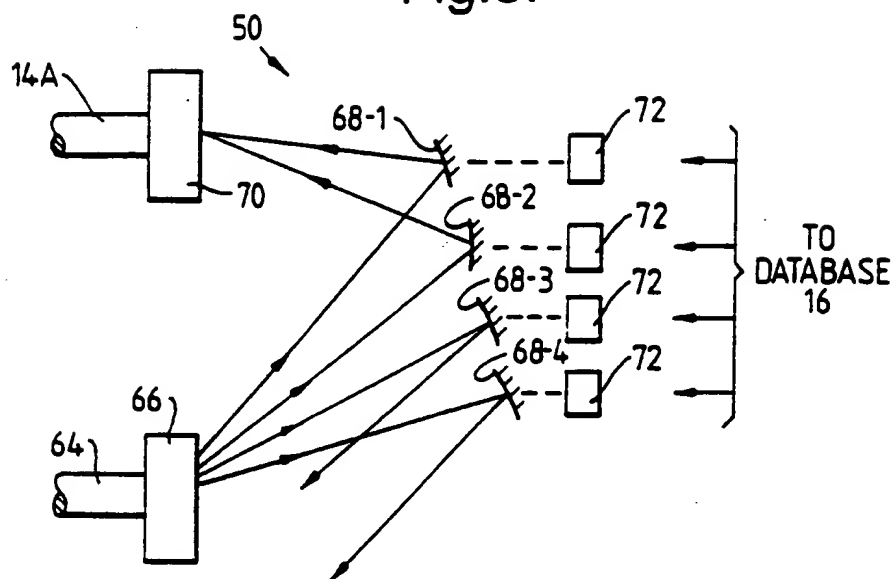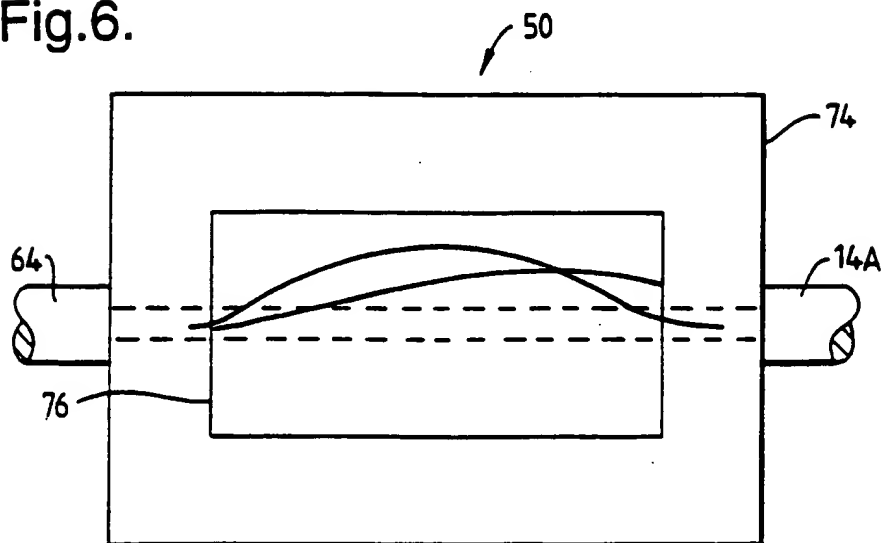wavelengths of the pairs in an adjacent group.

Fig.1.

Fig.2.

Fig.3.

Fig.4.

Fig.5.

Fig.6.

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   H04Q11/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6   H04Q   H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	-/--	

| X | Further documents are listed in the continuation of box C. | | X | Patent family members are listed in annex. |

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 March 1995	0 7. 04. 95

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016	O'Reilly, D

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category°	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JOURNAL OF LIGHTWAVE TECHNOLOGY, vol.11, no.5/6, May 1993, NEW YORK US pages 714 - 732, XP396704 S.B. ALEXANDER ET AL 'A Precompetitive Consortium on Wide-Band All-Optical Networks' cited in the application	1,2,7,8, 10-13
Y	see page 716, right column, line 30 - line 46 see page 717, right column, line 28 - line 31 see page 718, right column, line 52 - line 56 see page 719, left column, line 7 - line 21 see page 719, right column, line 9 - line 23 see page 720, left column, line 11 - line 15 see page 721, left column, line 36 - page 722, left column, line 36; figures 1-7 ---	3-6,9
X	WO,A,92 18890 (THE TRUSTEES OF COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK) 29 October 1992 cited in the application	1,2,7,8
Y	see page 5, line 5 - page 6, line 29 see page 7, line 3 - line 21 see page 9, line 8 - line 32 see page 14, line 4 - line 20 see page 16, line 8 - page 17, line 30; figures 1-5 ---	9-13
X	JOURNAL OF LIGHTWAVE TECHNOLOGY, vol.11, no.5/6, May 1993, NEW YORK US pages 937 - 950, XP396723 T.E STERN ET AL 'Linear Lightwave Networks: Performance Issues' cited in the application	1,2,7,8
A	see abstract see page 938, right column, line 17 - line 23 see page 941, left column, line 33 - line 38 see page 944, left column, line 40 - right column, line 25; figures 5-10 --- -/--	3-6,9,11

2 .

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CONFERENCE RECORD, IEEE GLOBAL TELECOMMUNICATIONS CONFERENCE, 2-5 DEC. 1990, VOL. 3 PAGES 1866-1872, SAN DIEGO US, XP218892 T.E. STERN 'Linear Lightwave Networks: how far can they go?' cited in the application	1,2,7,8
A	see abstract see page 1866, right column, line 17 - line 46 see page 1867, left column, line 18 - line 44 see page 1870, left column, line 1 - line 14; figures 4-6	3-6,9-13

Y	CONFERENCE RECORD, INTERNATIONAL CONFERENCE ON COMMUNICATIONS, 14-18 JUNE 1992, VOL. 3 PAGES 1173-1179, CHICAGO US, XP337910 S.S. WAGNER ET AL 'Multiwavelength Ring Networks for Switch Consolidation and Interconnection' cited in the application see abstract see page 1173, right column, line 40 - page 1174, left column, line 4 see page 1175, left column, line 28 - right column, line 11 see page 1177, right column, line 13 - line 52; figures 1-7	3-6,9

Y	PROCEEDINGS, SEVENTH ANNUAL JOINT CONFERENCE OF THE IEEE COMPUTER AND COMMUNICATION SOCIETIES, INFOCOM '88, 29-31 MAR. 1988, PAGES 354-362, NEW ORLEANS US, XP44787 G.R. HILL 'A Wavelength Routing Approach to Optical Communications Networks' see the whole document	9-13

A	IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATION, vol.8, no.6, August 1990, NEW YORK US pages 995 - 1004, XP471589 M.S. GOODMAN ET AL 'The LAMBDANET Multiwavelength Network: Architecture, Applications and Demonstrations' see abstract see page 997, left column, line 27 - line 41; figure 3	1-13

2

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
WO-A-9218890	29-10-92	US-A-	5191626	02-03-93
		EP-A-	0581888	09-02-94
		JP-T-	6509655	27-10-94